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VVER WORKING GROUP

Preliminary Analyses & Comparison of Design differences between VVER-1000 Reactors

Regulators involved in the VVER working group discussions:	AERB, HAEA, NNSA (and NSC as its TSO), Rostechnadzor (and SEC NRS as its TSO), and NDK
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TABLE OF CONTENTS

Preliminary Analyses & Comparison of Design differences
between VVER-1000 Reactors

Chapter 1 Overview of the VVER Design

1.1 Introduction

VVER reactors are a series of Pressurised Water Reactors (PWRs), originally designed by OKB Gidropress – a subsidiary of ROSATOM – Russian state nuclear corporation, while the nuclear power stations employing VVER technology have been developed by the power plant design institutions within ROSATOM, such as Moscow ATOMENERGOPROEKT (AEP), St. Petersburg AEP and Nizniy Novogorod AEP.

The first-ever construction of a VVER nuclear power plant in the world started way back in 1960s and was commissioned in 1964, at Novovornezh Nuclear Power Plant in the Voronezh region of Russia. This unit was then called as V-210 and the second unit at Novovornezh-2 was called as V-365, wherein, initially, these numbers referred to the corresponding electrical output of the main generator of the unit

Since then, it has been long way forward for VVER type of reactors. About 67 reactors have been constructed in many parts of the world, such as Armenia, Bulgaria, China, Czech Republic, Finland, Hungary, India, Iran, Slovakia, Ukraine and, above all, Russia – where it originated.

The successful commissioning and operation of the above two units at Novovoronezh virtually set the platform and provided the solid basis for further development of more powerful reactors. Subsequently Generation-II VVERs (1966-1980) were developed included additional safety features such as emergency core cooling and auxiliary feed water systems as well as upgraded accident localisation systems. These VVER-440 units have been safely operating in many European Union nations.

Based on the experience and success of Generation-II reactors, the design and development of Generation-III reactors was taken up and VVER-1000, which came to be known as the flagship of VVER design, was developed through this effort.

The VVER-1000 was first constructed at Novovoronezh 5 (VVER-1000/V-187) put in operation in 1981. The Unit is provided with a containment designed to withstand maximum pressure for "maximum" design basis accident involving a rupture of the main circulation pipeline with the diameter (D_{nom}) 850 mm.

The VVER-1000/V-187 design solutions were further implemented in the 'small series' designs of VVER-1000/V-302 (South Ukraine 1) and VVER-1000/V-338 (Kalinin 1 and 2), and later in VVER-1000/V-320 ('large series') (Zaporozhye, Balakovo, Kalinin 3 and 4, Rostov, Kozloduy, Temelin, etc.).

Table 1.1 below gives a list of the design modifications of the VVER-1000 and VVER-1200 plants.

Table 1.1. List of VVER-1000 and VVER-1200 design modifications

	modif.	*NPP site*	*Units*	*country*	*remarks*	*start*
VVER-1000	V-187	Novovoronezh	1	Russia	head unit	1981
	V-338	Kalinin	1, 2	Russia	'small series'	1983…
	V-302	S-Ukraine	1	Ukraine		
	V-338	S-Ukraine	2	Ukraine		
	V-320	Balakovo	1, 2, 3, 4	Russia	'large series'	1984…
		Rostov	1, 2, 3, 4	Russia		
		Kalinin	3, 4	Russia		
		Zaporozhe	1, 2, 3, 4, 5, 6	Ukraine		
		Rivno	3, 4	Ukraine		
		Khmelnizk	1, 2	Ukraine		
		S-Ukraine	3	Ukraine		
		Temelin	1, 2	Czech		
		Kozloduy	5, 6	Bulgaria		
	V-412	Kudankulam	1, 2, 3, 4, 5, 6	India		2014…
	V-428	Tianwan	1, 2, 3, 4	China		2007…
	V-446	Busher	1	Iran		2013
	V-528	Busher	2	Iran		
VVER-1200	V-392M	Novovoronezh-2	1, 2	Russia		2017…
	V-491	Leningrad-2	1, 2, 3, 4	Russia		
	V-491	Belarus	1, 2	Belarus		
	V-509	Akkuyu	1, 2	Turkey		
	V-510K	Kursk-2	1, 2, 3, 4	Russia		
	V-510	Smolensk-2	1, 2	Russia		
	V-522	Hanhikivi	1	Finland		
	V-523	Rooppur	1, 2	Bangladesh		
	V-527	Paksh-2	1, 2	Hungary		
	B-529	Al-Dabaa	1, 2, 3, 4	Egypt		

1.2 Main characteristics of reactor installation of VVER-1000 design

This chapter addresses a comparison of key design characteristics of Balakovo NPP Unit 4 (in Russia), Kudankulam NPP Units 1&2 (in India), and Tianwan NPP Units 3&4 (in China).

Balakovo 4 (VVER-1000/V-320) is a reference plant for the Kudankulam NPP (VVER-1000/V-412) in India and the Tianwan NPP (VVER-1000/V-428) in China.

The main differences in the design characteristics are shown in Appendix 1.

1.3 Reactor and Reactor Coolant System

The main distinguishing features of the VVER compared to other PWRs are:

- Horizontal steam generators
- Hexagonal fuel assemblies
- No bottom penetrations in the pressure vessel
- High-capacity pressuriser providing a large reactor coolant inventory

The primary purpose of reactor coolant system (RCS) is to transfer the heat generated in the reactor core to the steam generators where steam is produced. The borated de-mineralised water coolant of RCS also acts as a neutron moderator and reflector and as a solvent for the neutron absorber used in chemical shim control. The RCS pressure boundary provides a barrier against the release of radioactivity generated within the reactor and is designed to ensure a high degree of integrity throughout the life of the plant.

The RCS, of water-cooled water moderated power reactor VVER-1000 comprises of reactor pressure vessel, four reactor coolant loops, and the pressurising system connected to one of the reactor coolant loops.

Vertical reactor pressure vessel (with the reactor upper unit) contains reactor internals: reactor core, barrel and baffle of reactor core, protective tube unit, surveillance-specimens, control rods, and in-core instrumentations. The reactor upper unit comprises the electrical connections assembly. The reactor core barrel with spacer grid provides the stable geometry of the reactor core. The spacer grid together with the protective tube unit is intended to position and fix each fuel assembly in the reactor.

Each reactor coolant loop contains a primary coolant pump, a horizontal steam generator, and primary coolant pipelines. The pressure vessel forms the anchor point of the RCS. The steam generators and reactor coolant pumps are mounted with flexibility to accommodate thermal expansion. The pressuriser connected to the hot leg of one of the circulation loops by the surge line, serves to maintain the pressure in the reactor coolant system and to compensate for short time changes in coolant volume.

The coolant in the primary circuit is kept under pressure to keep it sub-cooled during plant operation. The thermal-hydraulic design of the RCS rules out nucleate boiling in the fuel assemblies and also guarantees optimum selection of steam generator size and reactor coolant pump power. The sub-division of RCS into a number of loops make it possible to continue operating the reactor system on three or two loops at correspondingly reduced power in the event of failure of one or two reactor coolant pumps. Since the water transfers all the heat from the core and is irradiated, the integrity of this circuit is crucial. Four main components can be distinguished:

a) Reactor vessel: Water flows through the fuel rod assemblies which are heated by the nuclear chain reaction.

b) Pressuriser: To keep the water under constant but controlled pressure, the volume compensator regulates the pressure by controlling the equilibrium between saturated steam and water using electrical heating and relief valves.

c) Steam Generator: In the steam generator, the heat from the primary coolant water is used to boil the water in the secondary circuit.

d) Main coolant Pumps: The pump ensures the proper circulation of the water through the circuit.

Chapter 2 Safety Systems

2.1 Reactivity Control

Control rods with ingenious mechanisms ensure reliable operation. The control rod mechanisms located atop the reactor pressure vessel (RPV) are used for driving the control rods 'in' to different extents in order to reduce the reactivity and, consequently, the power output of the reactor. Electromagnetic clutches hold these rods and, upon loss of electricity, these clutches are 'de-energised,' which causes the control rods to fall freely into the reactor core under the force of gravity, making the reactor subcritical in a matter of 2 to 4 seconds.

Reactor control and protection system (CPS) uses absorber control rods (CPS AR) that contain absorbing elements. Control rods are grouped in 10 banks. A ShEM-3 type actuator is used to drive the absorber control rods in/out of the core.

There are totally 61 CPS ARs at Balakovo 4, with each AR consisting of 18 absorbing elements.

There is also emergency boron injection system implemented in Balakovo NPP, consists of three independent trains, each incorporating a pump, pipelines, valves, and emergency tanks with concentrated boric acid solution. It's supply at least 6 m^3/h of boric acid solution (with boron concentration ranging between 39.5 and 44.5 g/dm^3), whatever the primary circuit pressure.

At Kudankulam NPP, a larger number of control rods (121) provide greater safety margins. Further, quick boron injection system, based on the principle of diversity, acts as a backup system to the above mentioned 'control rod' mechanism for achieving reactivity control and quick shutdown. There are two components of the quick boron injection system – active and passive. The system injects concentrated boric acid solution into the reactor coolant circuit using pumps (active functionality), but this system can work even in case of failure of power to the pumps, as these are then driven by 'flywheels' connected to the pumps. The flywheels have a passive functionality, as they work on the principle of inertia (conservation of momentum). The conserved energy drives the pumps for a time period that is sufficient enough to achieve the injection of the boric acid solution

In Tianwan NPP Unit 3&4, there are also control rods system and emergency boron injection system. The control rods system consists of 103 RCCAs in the balance cycle. Maximum possible number of RCCAs is 121 according to the number of nozzles on the reactor top head, intended for installing the RCCA drives.

Emergency boron injection system (JDH) consists of four independent and physically separated trains. And each train is connected to borated water storage tanks JNK10,40BB002, with a concentration of 40 gH_3BO_3/kgH_2O and a volume of 150 m^3. At design basis accidents of loss-of-coolant from primary to secondary circuit, the system injects boric acid solution into the pressuriser. At Beyond Design Basis Accidents with an anticipated operational event after a failure of scram (ATWS), the system injects a highly concentrated boric acid solution (40 gH_3BO_3/kgH_2O) into primary circuit to rapidly bring the reactor to sub-criticality.

2.2 Emergency Core Cooling System

Emergency Core Cooling System (ECCS) is employed in case of an unlikely scenario to flood the reactor core with ECCS water containing boric acid.

The ECCS is designed to inject concentrated boric acid solution in the primary circuit in reactivity-initiated accidents, loss-of-coolant events in primary / secondary circuit, and in loss-of-power emergencies.

The ECCS includes an active part – a high-pressure ECCS (HP ECCS) and a low-pressure ECCS (LP ECCS), and a passive part (hydraulic accumulators – HA ECCS).

The HP ECCS consists of three independent trains, each incorporating a pump, pipelines, valves, and emergency tanks with concentrated boric acid solution. In emergency, the HP ECCS would supply at least 130 m^3/h of boric acid solution (with boron concentration ranging between 39.5 and 44.5 g/dm^3), under the primary circuit pressure of 9.0÷1.5 MPa.

The LP ECCS has three independent emergency core cooling trains, each comprising a pump, a sump tank, an ECCS heat exchanger, pipelines, and valves. The LP ECCS is capable of supplying in emergency at least 230 ÷ 750 m^3/h of boric acid solution (with boron concentration 16 g/dm^3) under the primary circuit pressure of 2.1÷0.1 MPa.

The LP ECCS is also intended to remove residual heat from the core during normal primary circuit cooldown at a specified rate (planned cooldown), and in emergency (emergency cooldown in shutdown modes with a non-tight primary circuit). Another function of the LP ECCS is to provide cooling in outage conditions, when the reactor head is off.

The ECCS hydraulic accumulators provide emergency supply of boric acid solution under the primary circuit pressure below 5.9 MPa. There are four mutually independent ECCS hydraulic accumulators at the Unit. Each accumulator is connected to the reactor vessel by a Dnom 300 mm pipeline. Two ECCS HAs supply boric acid solution to the upper part of the core, and the other two HAs – to the bottom part of the core.

In case of a design basis accident (DBA) with loss-of-coolant in the primary circuit at Balakovo NPP, the heat will be removed from the core by boron solution injection into the core: in the first stage by the HP ECCS and HA ECCS; and in the second stage by the LP ECCS.

In Indian VVERs (Kudankulam), ECCS has two components: passive ECCS and active ECCS. The passive ECCS does not require any pump or power supply and can function even during a highly unlikely scenario station blackout conditions. This passive part of the ECCS consists of special accumulator tanks that are connected using independent nozzles to reactor pressure vessel (RPV) from an elevated location above the RPV. There is also a provision of another passive system holding additional water at an elevated location above the RPV, which releases water slowly for an extended period during an emergency, to keep the core flooded. The passive ECCS is backed up by an active ECCS that uses pumps and derives its functionality from 4 channels of high-pressure and 4 channels of low-pressure subsets.

It should be mentioned that unlike Balakovo 4, the Kudankulam uses 2nd stage hydraulic accumulators, which is intended for the performance of the passive supply of boric solution into reactor core with the purpose of maintaining the level of coolant in the core in case of accidents with loss-of-coolant (for 24 hours after beginning of accident).

In Tianwan NPP Unit 3&4, the ECCS consists of three parts, a high-pressure safety injection system (HP ECCS), a low-pressure safety injection system (LP ECCS), and a passive part of hydraulic accumulators (HA ECCS). The high-pressure safety injection system (JND) is composed by four completely separate and physically isolated trains. When the coolant system pressure below working parameters of high-pressure safety injection system (less than 7.9 MPa), the system supplies boric acid solution of concentration 16 $gH_3BO_3/kg\ H_2O$ and temperature not less than 70℃ into the primary circuit with flow of 44.4l/s (160m3/h) at the primary pressure being 4.9 MPa, and with flow of 59.6l/s (214.6m^3/h) at the primary pressure being 2.0 MPa. The low-pressure safety injection system (JNG1) is composed also by four similar independent trains. The system carries out its assigned functions under loss-of-coolant accidents, if it supplies boric acid solution of concentration 16g $H_3BO_3/kg\ H_2O$ and temperature not less than 70℃ into the primary circuit with flow of 88.9 kg/s (320 m^3/h） at the primary pressure being 2.2 MPa, and with flow of 200 kg/s (720 m^3/h）at the primary pressure being 0.93 MPa. The ECCS passive part is composed by four ECCS accumulators, pipelines and valves. Solution inventory in three accumulators has an acceptable inventory during design basis accident to cool the reactor core in the interval before connection of the active part LP ECCS. The ECCS passive part can give a quick supply of boric acid solution into the reactor for core cooling and its flooding during loss-of-coolant accidents (LOCA), when the primary pressure drops below 5.9 MPa.

2.3 Containment

The VVER-1000 plants have a pre-stressed reinforced concrete containment made as a cylinder with a hemispherical dome on top.

Balakovo 4 uses a single-wall containment.

Kudankulam NPP has a double containment, with an inner shell made of pre-stressed reinforced concrete, and an outer non-stressed reinforced concrete envelope. The design provides venting of the inter-wall space and collection of potential inner leaks (from inner shell).

In Tianwan NPP, the containment is a double containment (inner and outer) ensuring the maximum protection against effect of accidental radioactive releases into the environment.

The inner containment is a structure made of pre-stressed reinforced concrete consisting of a cylindrical part and hemispherical dome. The containment inner surface is lined with carbon steel to make the containment leak-tight. The pre-stressed containment takes up the accidental design overpressure of 0.4 MPa and design overpressure of 0.46 MPa at the strength tests.

The outer containment is constructed in monolithic reinforced concrete with conventional non-stressed reinforcement and consists of a cylindrical part and spheroid-type dome. Between the outer and inner containments in the cylindrical part there is an annular space. The outer containment ensures the inner containment protection against such external effects as missile fall, air shock wave.

2.4 Containment Spray System

VVER-1000 reactors have a provision of containment spray system, which removes the heat released into the reactor containment, for example, in case of a break in the coolant pipeline resulting in release of steam inside the containment. The sprinkler system is automatically activated the moment pressure inside the containment crosses a predetermined value.

The spray system at Balakovo 4 performs the following functions:

- minimises containment pressure and temperature in accident conditions;
- binds the free iodine present in the containment environment in case of an accident;
- prevents or minimises release of radioactive substances outside the containment, and
- provides a make-up of the spent fuel cooling pool (in case of unavailability of a system delivering cooling water to the SNF cooling pool).

The spray system starts up when containment pressure reaches 0.03 MPa. The system consists of three independent trains. The train lines run to the area beneath the containment dome to form there open rings, with 20 jets setting on each ring. The jets spray water with specified dispersion and under a specified angle so as to ensure a uniform spraying throughout the containment space.

In Kudankulam NPP, containment spray system has two redundant channels of sprinklers that spray water in the space within the containment dome. Condensing the steam, the containment spray system limits the temperature and pressure peaks to values at which containment integrity is assured. The spray water also contains chemicals to bind fission products, thus confining any radioactive fission products that may be released inside the containment building during a primary system leak.

In Tianwan NPP Unit 3&4, the containment spray system (JMN) consists four similar trains being completely independent from each other. The containment spray system performs the following functions:

- Minimises containment pressure and temperature during LOCA accidents,
- In LOCA accidents, it will change to operation from the containment sump when the level in borated water storage tanks below the standard 0.25m,
- Residual heat removal and reactor cooldown during normal shutdown （cooperate with residual heat removal system JNA,
- Filling of the reactor internals inspection shaft in 24 hours after beyond design basis accident related to reactor core melting and corium relocation beyond the reactor pressure vessel.

Under emergency conditions with leakage the system performs its specified function of pressure reduction within the containment, in case it ensures injection of the boron solution at a concentration no less than 16g/kg, flowrate no less than 416.6kg/s (1500t/h) to the containment air space.

This system is capable to reduce the pressure within the containment at least down to 50% maximum rated value during 24 hours. In the event of a design basis accident, the system could keep both the release of radioactive products and the radioactivity levels in the environment within standard limits. The spray system performs binding of iodine in the containment steam-air ambient under emergency conditions with primary coolant leakages by adding the chemicals into spray water.

2.5 Overpressure Protection

In VVER-1000 reactors, there are two kinds of overpressure protection systems. One is primary circuit overpressure protection. The other is secondary circuit overpressure protection.

Balakovo 4 has a primary circuit overpressure protection system. The system function is to partially discharge primary coolant from pressuriser to pressure suppression pool (bubbler) by opening and closing pulse safety devices under specified pressure. Furthermore, owing to the solenoid drives of the safety device pilot valves, the system is capable of reducing (upon MCR command) the primary circuit pressure to 9.0 MPa in a controlled way, with the initial pressuriser pressure level at least 11.8 MPa. This action, implementing together with emergency gas removal system, allows to provide boric acid solution supply to primary circuit from boron injection pumps, if necessary.

The primary circuit overpressure protection system comprises three pulse safety devices installed in parallel in a pipeline of primary coolant discharge from pressuriser steam section to bubbler. One pulse safety device is a control device, and the others are working devices. The control safety device has lower pressure setpoint than the working devices.

Balakovo 4 is equipped with a secondary circuit overpressure protection system intended to prevent steam generator pressurisation above 9.0 MPa. For this, two pulse safety devices consisting of a main and pilot valve are installed in the steam lines of each steam generator. Pilot valve controls the main valve operation.

In Kudankulam NPP:

- For the primary circuit overpressure protection, three pulse safety devices (PSDs) are installed on the top of the pressuriser in VVERs of Kudankulam. The PSDs are passive component for which we do not need to apply single failure assumption;
- For the secondary circuit overpressure protection, 8 PSDs are installed on the main steam lines in VVERs of Kudankulam, two on each main steam line. The PSDs are passive component for which we do not need to apply single failure assumption.

In Tianwan NPP, for the primary circuit overpressure protection, there are 3 pulse safety devices (PSDs) on the top of the pressuriser, each PSD consisting of:

- main valve (MV);
- two spring pilot valves (PV) with an additional electromagnet load;
- two motor-operated valves mounted in series;
- hand-operated isolation valves.

Motor-operated valves allow to keep the MV in open position at PRZ pressure within the range from 0.5 Mpa to the values of actuation of PV of direct action. Control of motor-operated valves is made both from pressure pick-ups and temperature sensitive elements, and remote control from panel of MCR and ECR.

Secondary circuit overpressure protection includes three steps:

- The first protection – turbine bypass system (MAN) which discharges steam into the turbine condenser and makes up 60% of the summary capacity of the steam generators. The open pressure of turbine bypass steam valve (BRU-K) is 6.62MPa+0.05MPa.
- The second protection – quick-acting steam generator relief valve (BRU-A) makes up 60% of capacity of the steam generators.
- The third protection – safety valves. Two safety valves (2x100%) are installed nearby each steam generator.

2.6 Support Systems

Support safety systems at Balakovo 4 includes:

- emergency power supply system (EDGs) – 3x100% (See also para 4.2);
- reliable power supply system for Category 1 and 2 loads of any voltage, including cabling – 3x100%;
- air supply system for pneumatically driven valves – 3x100% (to valve drives);
- essential service water cooling system (ESSW) for reactor compartment – 3x100% (using spray ponds as an ultimate sink, with the make-up from Saratov water reservoir or cooling pond);
- supporting ventilation systems with system-specific redundancy levels.

Apart from these, there are fire protection systems, also classed as support safety systems, to ensure design basis performance of safety systems in case of fire hazards.

Balakovo 4 design does not treat essential component cooling system (intermediate circuit) as a support safety system.

At Kudankulam NPP, there are several safety related systems to support safety systems as follows:

- Emergency Diesel Generators (EDGs) – 4x100%;
- Component Cooling Water System (CCW) – 4x100%;
- Essential Service Sea Water Cooling System (ESSW) – 4x100%;
- Essential Chilled Water System;
- Main control room Habitability Systems.

In Tianwan NPP，support safety systems include:

- Emergency Diesel Generators (EDGs) – 4x100%;
- Emergency Power Supply System (EPSS)– 4x100%;
- Component Cooling Water System (KAA) – 4x100%;
- Essential Service Sea Water Cooling System (PEB) – 4x100%;
- Main Control Room Habitability Systems (SAC11)– 3x100%.

Apart from these, there are fire protection systems, also classed as support safety systems, to ensure design basis performance of safety systems in case of fire hazards.

Chapter 3 Severe Accident Management Systems

3.1 Core Cooling

Balakovo 4 design does not include passive heat removal systems, though there are facilities (mobile equipment) specially designated for BDBA management– See para 3.4.

Passive Heat Removal System (PHRS) is a unique safety feature of Kudankulam NPP. The system is designed to provide emergency reactor core cooling even in the worst-case scenario of total loss of electrical power at the plant, including loss of grid power and backup power. This amazing level of safety is achieved through passive 'thermo-siphoning' and it works on the natural principle of convection, using air ducts. Heat from the reactor is transferred to the large quantity of water present on the secondary side of the steam generators and this water in turn is cooled by atmospheric air in the coolers provided at a height on the outside of the outer containment. The hot air rises naturally and is removed through outlet ducts, while cooler air enters through inlet ducts. A natural circulation is established and heat is removed without using any power at all.

In Tianwan NPP Unit 3&4, PHRS was not designed. In severe accident core cooling is ensured by supplying water to SGs with the mobile diesel pump.

3.2 Hydrogen Control

During a degraded core accident, hydrogen is generated at a greater rate than that of the design basis LOCA. The containment hydrogen control system of VVERs is designed to accommodate the hydrogen generated from the metal-water reaction of 100 percent of the active fuel cladding and limit the average hydrogen concentration in containment for a degraded core accident. These limits are imposed to preclude detonations in containment that might jeopardise containment integrity or damage essential equipment.

The containment hydrogen control system consists of a system of passive catalytic hydrogen recombiners (PCHRs). The PCHRs are capable of controlling hydrogen in all accident sequences with moderate hydrogen release rates, and are located throughout the containment.

To ensure hydrogen safety, Balakovo 4 is provided with two mutually independent systems, a system to remove hydrogen from the containment in emergency, and a system to control hydrogen concentration in the containment.

The emergency hydrogen removal system uses passive catalytic hydrogen recombiners (PCHRs) placed in the containment in potential hydrogen accumulation areas. There are totally 67 PCHRs of the RVK-1000 type and 53 PCHRs of the RVK-500 type. The number of the PCHRs was chosen based on the BDBA safety analysis assuming a potential simultaneous damage of up to 10 % PCHRs of their total inventory at the Unit.

The system controlling the hydrogen concentration in the containment employs hydrogen gas analysers and combined hydrogen and oxygen gas analysers. The system includes 14 hydrogen gas analysers (of the GV-01 type); 6 combined hydrogen and oxygen gas analysers (of the GVK type), and gauges measuring the containment temperature.

In Kudankulam NPP, there are 154 PCHRs located throughout the containment

In Tianwan NPP Unit 3&4, hydrogen removal system (JMT) is designed for operation under design basis and beyond design basis accidents. Under design basis accidents the system maintains a hydrogen concentration in water steam and air mixture lower than the concentration limits of the flame propagation within the design range of medium parameters changing in the under-containment premises. Under BDBA, which can maintain a hydrogen concentration at level excluding a rapid combustion progress in large volumes. In order to remove hydrogen from the containment, there are two standard sizes of passive catalytic hydrogen recombiners: PARQX-150 and PARQX-75.The total number of recombiners in the flowchart is 44. Recombiners are divided into 8 process groups according to the location point and capacity. The hydrogen removal system does not have active part and does not need reliable power supply.

3.3 Core Catcher

After reactor vessel failure, core debris is discharged into the containment and Molten Core Concrete Interaction (MCCI) begins, leading to erosion of the concrete in the reactor vessel cavity. This threatens the integrity of the containment pressure boundary due to the possibility of melt-through of containment liners and the concrete basemat.

The reactor cavity is configured to promote retention of, and heat removal from, the postulated core debris during a severe accident, thus serving several roles in severe accident mitigation. The large cavity floor area allows for spreading of the core debris, enhancing its coolability within the reactor cavity region. The containment liner plate in reactor cavity area is embedded in the concrete.

Balakovo 4 design does not provide for a corium catcher, though there are facilities (mobile equipment) specially designated for BDBA management – See para 3.4.

In Indian VVERs, a massive steel tank type containment device located beneath the reactor core in each of the KKNPP reactor buildings, In the worst-case scenario, even if the highly improbable event of fuel meltdown occurs, the core catcher would hold any molten fuel escaping through the bottom of the reactor. The core catcher also contains ferrous oxide and aluminium oxide bricks that would absorb the heat and themselves melt, and thus bring the temperature down, while also causing the fuel to form lumps, thereby preventing any seepage of radioactive material either to the bottom of the plant or into the ground. For additional cooling, the area outside the core catcher is flooded with water

The core catcher located beneath the reactor core in Tianwan NPP. During a severe accident accompanied by the degradation of the core and failure of the reactor pressure vessel, the core catcher traps liquid and solid debris of degraded core, elements of reactor pressure vessel, and reactor internals. The core catcher contains sacrificial materials made of ferrous oxide and aluminium oxide which are used to react with Corium， in order to make Corium anchored and cooled within the under reactor space in the concrete cavity for an unlimited period of time. In order to remove heat from the corium released into the core catcher, the core catcher includes heat exchangers, valves and pipelines. It is cooled with water drained by gravity from the RI inspection shaft and spent fuel pit. Vapour generated in the heat exchanger is drained through the upper channels into the containment atmosphere. Water inventory is sufficient to provide gravity flow into the core catcher for 24 hours of NPP blackout.

3.4 Post-Fukushima Safety Enhancements

To cool the core in a BDBA, Balakovo 4 has a capability to supply boric acid solution and water from the ECCS HA, LP ECCS, and HP ECCS, and to use mobile equipment. Also, residual heat can be removed from the core via the secondary circuit owing to water evaporation in steam generators. Boric acid solution is supplied to:

- Primary circuit (to the TQ23,33D01 pumps outlet) by connecting a mobile pump facility PNU150/900 (flow rate up to 150 m^3/h under the primary circuit pressure up to 90 kg/cm^2);
- SNF cooling pool (into the TQ21,31D01 pumps outlet) by connecting PNU40/50 (flow rate up to 40 m^3/h).

In case of a total loss of off-site and on-site power, the active part of the ECCS will be powered from two mobile DG facilities (with the capacity of 2 MW and 0.2 MW). The SG make-up will be provided by EFWP (powered from mobile DGs), and by PNU 150/900 or PNU 150/120.

The system delivering water to essential loads from motor pumps (using PNU 500/50) is designed to prevent the progression and mitigate a BDBA involving a total loss of a.c. sources or another BDBA causing long-term unavailability of service water supply to essential loads in the nuclear island (category 'A'), including loss of water in intake chambers of backup diesel generator station (BDGS).

The water supply system from motor pumps consists of two subsystems:

- a subsystem delivering water to outlet pipelines of pumps QF21.31D01.02;
- a subsystem delivering water to inlet chambers of BDGS-2, 3.

To further enhance the defense-in-depth safety paradigm and to take safety to the next level, Kudankulam NPP has been provided with additional measures to cope up with rare multiple natural events of extreme rare probability. These measure take care of hypothesised extended station blackout conditions, like the one happened in Fukushima

a) A separate 8000m3 water tank at higher elevation,

b) Scheme for make-up of water to spent fuel pools,

c) Scheme for charging water to secondary side of steam generators,

d) Scheme for injection of borated water to reactor coolant systems from a separate 160m3 borated water storage tank outside reactor building,

e) Scheme for providing backup power supply to relevant valves and pumps.

In Tianwan NPP Unit 3&4, the following measures are taken for improvement after Fukushima accident:

A. Building water retaining wall and waterproof sealing of holes in reactor plant outer wall.

B. Mobile diesel pump is used to supply water to any of the four SGs or spent fuel pool.

C. Connection interfaces for 6KV emergency section and 400V emergency section are designed to match the 6KV and 400V mobile diesel generator.

D. Additional power supply under accident to the spent fuel pool level-meter and temperature gauge from mobile diesel generator.

Chapter 4 I&C and Electrical System

4.1 I&C System Platform

The I&C part of the reactor control and protection system at Balakovo 4 is designed to:

- monitor reactor facility parameters;
- control reactivity in all operating modes of the reactor facility;
- control reactor power, including regular and emergency shutdown,
- bring reactor in a subcritical state in abnormal conditions and in accidents (violation of design basis limits), and provide reactor hold-down;
- send information about monitored parameters and availability of system components to the main control room and the emergency control room to pass on to relevant systems.

The configuration and design of the reactor emergency protection (scram) system, the neutron flux instrumentation and the instruments processing the signals of process parameter sensors ensure the fulfilment of the reactor scram function considering single failure combined with simultaneous occurrence of the most 'severe' initiating event – a fire causing a failure of one of the reactor scram sets.

Balakovo 4 has a process control safety system (PCSS) designed to control the protective actions of safety systems. The PCSS has subsystems for process control, remote control, interlocks and protections, process alarms, and self-regulation. These subsystems are designed to bring into action the process protection, support, and confinement safety systems, and to monitor and control their performance when implementing protective functions. The PCSS hardware includes:

- primary transducers essential to generate signals to trigger process protection, support and confinement facilities;

- individual instrumentation for safety related parameters;
- instruments to process primary transducer signals, weight them against the setpoints, and process discrete signals of protections and interlocks following a specified logic; automatic and remote controls for protection, support and confinement hardware.

Balakovo 4 has the following design solutions:

- there are three mutually independent trains of control safety system components;
- the train independence is provided by each train having its own stand-alone power sources, a stand-alone set of monitoring and control (automatic and remote) equipment, including instrumentation; by the absence of electrical links between trains, and by physical separation of trains;
- the safety systems come into action automatically in a process accident triggering appropriate process protections. The system trains use 6 kV sections as a power source, and if these are unavailable, the systems connect to an emergency power source - a diesel generator following a load pickup sequence;
- the MCR/ECR operator receives information on control system performance separately for each safety system train.

Furthermore, to achieve a high-level reliability, some CSS components have majority voting in each safety system train. Thus, for example, the analogue circuits and the logic part of the protections in each CSS train have '2 out of 4' voting. The power supply to each protection train etc. is provided by stand-alone facilities.

I&C system for Kudankulam NPP is built to provide control and monitoring in different modes like normal operation and accident conditions of VVER type of reactor units. It is designed as an integrated system, governed by the requirements and features of the process systems, equipment's and layout of nuclear power plant. I&C system incorporate following features:

a) reactor emergency protection;
b) automated operation of safety systems;
c) automated logical control (protections / interlocks);
d) automated regulation (both continuous and on-off control);
e) manual control (remote) by operator from the control panels or work stations;
f) monitoring of plant parameters on panels and workstations;
g) on line equipment diagnostics and testing;
h) alarm annunciation and data archiving;
i) control of systems from local panels.

Structure of I&C has a hierarchical principle and has two levels as follows:

a) Lower Level Control
b) Upper Level Control

The Reactor Trip System called as 'Emergency Protection (EP)' system is used for safe shut down of the reactor. It consists of 2 identical sets each having 3 independent channels based on 2/3 logic. The emergency protection is designed for

a) Monitoring the reactor parameters.
b) Bringing reactor into subcritical state by dropping all control rods by gravity into the reactor core - when any parameter (25 Trip Parameters) reaches the safety limits or by operator action.
c) Maintaining the reactor in subcritical state.

Apart from EP, Preventive Protection (PP) is applied in case of operational occurrences, to prevent the reactor scram and is applied prior to EP. Three kinds of preventive protections are provided.

a) Set back or Preventive Protection of first kind (PP1)
b) Hold back or Preventive Protection of the second kind (PP2)
c) Step back or Accelerated Preventive Protection (APP)

C&I of Engineered Safety Features is termed as Engineered Safety Features Actuation System (ESFAS) and is provided to ensure the following:

a) Automatic reactor shutdown during Anticipated Transient Without Scram (ATWS)
b) Prevent or mitigate damage to the core and RCS equipment / components
c) Containment isolation during accident conditions

Following are salient features of ESFAS

a) 4 redundant and independent safety trains with triplicated channels are provided as Engineered Safety Systems.
b) Sensors for ESFAS are separate from sensors of EP system and Plant Control Systems except neutron detectors. Sensors of neutron detectors and Gamma measurement are shared with EP system with galvanic isolation.

In Tianwan NPP Unit 3&4，I&C system ensures a maximum of safety and availability of the plant during normal and accident conditions. It is designed as an integrated system, governed by the requirements and features of the process systems, equipment's and layout of nuclear power plant. I&C system in Tianwan incorporate following features:

a) protection system including the Reactor Trip System (RTS) and the Engineered Safety Features Actuation System (ESFAS);
b) safe shutdown systems;
c) information systems important to safety;
d) interlock systems important to safety;
e) control systems, not required for safety;
f) diverse instrumentation and control systems;

g) data communication systems;

h) supporting systems;

The design principle for I&C systems is characterised as "defense-in-depth". The overall safety of the plant is ensured by different levels of defense as follows:

a) Level I -prevention of anticipated operational occurrence(AOO)

b) Level II - operational occurrence mitigation

c) Level III - safety systems are actuated under design basis accidents(DBA)

d) Level IV - limitation of beyond design basis accident (BDBA) consequences

Protection Systems are those instrumentation and control systems, which initiate safety actions to mitigate the consequences of design basis events. They monitor and process the values of process variables relevant to the safety of the nuclear power station and to the state of the environment in order to detect incidents and to initiate protective actions so that the plant condition is kept within safe limits.

The protection systems include the Reactor Trip System (RTS) and the Engineered Safe Features Actuation Systems (ESFAS).

The Reactor Trip System automatically initiates the reactivity control system (control rods) to ensure that specified acceptable fuel design limits are not exceeded.

ESFAS are systems which initiate and control operation of the process safety systems, which remove heat or somehow else assist in maintaining the integrity of the three physical barriers intended to prevent spreading of the ionising radiation or radioactive contaminants into the environment (fuel matrix, fuel element claddings, reactor coolant pressure boundary, and containment).

Apart from EP, Preventive Protection (PP) is applied in case of operational occurrences, to prevent the reactor scram and is applied prior to EP. Three kinds of preventive protections are provided.

a) Preventive Protection type 1 (PP1)
b) Preventive Protection type2 (PP2)
c) Accelerated Preventive Protection (APP)

Besides the computer based digital RTS and the ESFAS, an additional Manual Actuation of Safety Systems (MASS) is implemented to provide the backup ESP actuation means to cope with the complete loss of safety functions due to CCF of the computer based digital Reactor Protection System.

4.2 Emergency Diesel Generator System

In the event of a complete loss of off-site power (LOOP), the Emergency Diesel Generator System (EDG) provides an on-site standby source of AC electric power to the safety related loads, such as the Engineered Safety Feature System (ESF) and equipment required to 1) safely shutdown the reactor, 2) maintain the reactor in a safe shutdown condition. The EDG is designed to attain rated voltage and frequency within 15 seconds. Once the EDG has reached rated voltage and speed, the diesel generator breaker closes and the sequencer generates proper signal to connect identified loads in emergency bus in a programmed time sequence.

In a loss-of-power accident at Balakovo 4, a backup DG station that is a stand-alone emergency power source would connect to buses of appropriate 6 kV section for Category 2 loads. Backup DGs are part of the three totally independent of each other trains in the emergency power supply system. Each EPS train supplies power to the loads assigned to this train. The BDGS equipment is located in three boxes completely isolated from one another. A DG starts up automatically in 15 s (from actuation command to being ready to pick up the load). The DG picks up the loads automatically following a load pickup sequence programme.

The capacity of EDGs of Kudankulam is 6300 MWe and the special features of Emergency Power Supply System (EPSS) include:

a) 4×100% independent power supply trains with DG backup for power supply to redundant trains of safety systems.

b) The emergency power supply system meets the single failure criteria i.e. it is capable of fulfilling its functions, which requires its operation on all initiating events due to the failure of one channel during postulated initiating event, coinciding with the failure of second channel as a result of independent failure of active or passive component of that particular channel (irrespective of initiating event) and the non-availability of third channel due to repair or maintenance of any active element of third channel.

c) Each train is provided with three battery banks - two of them are rated for two hour backup and the third one is rated for 24 hours for meeting SBO requirement.

d) Physical separation of each independent train is by provision of 3 h rated fire barrier.

e) Inhibition of operator control for initial 30 minutes in case of actuation of EDG sets through emergency transfer.

The capacity of EDGs of Tianwan Unit 3&4 is 5500 MWe，the features of Emergency Power Supply System (EPSS) include:

a) 4x100% independent power supply trains with DG backup for power supply to redundant trains of safety systems.

b) The emergency power supply system meets the single failure criteria.

c) Each train is provided with three battery banks -rated for two hour backup, There is a 150 kW mobile DG for BDBA conditions.

d) Physical separation of each independent train is by provision of 2h rated fire barrier.

e) Inhibition of operator control for initial 10 minutes in case of actuation of EDG sets through emergency transfer.

Appendix - 1

Comparison of VVER-1000 design characteristics

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
1	Design		VVER-1000/V-320	VVER-1000/V-412	VVER-1000/V-428
2	General information	General Designer	AEP, Moscow	AEP, Moscow	ATOMPROEKT, St.-Pt
		Nuclear Island Supplier	OKB Gidropress	OKB Gidropress	OKB Gidropress
		Turbine Island Supplier	Kharkiv Turbine Plant (now "Turboatom")	Power Machines	Harbin Electric Company Ltd
		Construction	since 1984	since 2002	since 2012
		Commercial Operation	since 1993	since 2014	since 2018
3	Reactor power	Thermal (MWt)	3120 [1)]	3000	3012
		Electrical (MWe)	1170	995	1126
4	Fuel	Max. enrichment	4.4%	5%	4.1%
		Fuel assembly type	TVS-2M	UTVS	TVS-2M
		Fuel assemblies number	163	163	163
		Control rods number	61	121	121
		Max burn-up	51.5 [MW-day/kgU]	55.0 [MW-day/kgU]	45.9 [MW-day/kgU]

[1] Following modification, Balakovo 4 has been operated at 104 % of the original design power level

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
5	Spent fuel pool	Capacity total	613 fuel assemblies	646 fuel assemblies	706 fuel assemblies
		Water inventory	~ 2820 m^3 (refuelling)	~ 1700 m^3	~ 1700 m^3
		Power of heat exchanger of cooling system	~20 MW	~20 MW	~17 MW
		Special technical means for SBO accident conditions	Cooling system of Spent fuel pool Water supply by spray system can be used	First-Of-A-kind systems – Hydro-accumulators of stage-2 and Passive heat removal system	(First-A-Kind) - RHR system of spent fuel pool (2x100% train with backup from 2 of 4 JMN trains
		Monitoring instrumentation for BDBA conditions	Measures for monitoring of water amount in spent fuel pool	Selected essential parameters are provided with battery backup for 24 hrs. After 24 hrs power requirements for these monitoring instruments is provided by mobile air-cooled DG.	Measures for monitoring of water amount in spent fuel pool
6	Reactor recirculation system	Number of loops	4 loops for primary coolant recirculation. Each loop at main cold pipeline is equipped by one main coolant pump		
		Main coolant pump	MCP type – GCN-195M, motor - with oil lubricant Capacity – 20000 m^3/h, average time to failure – not less 20000 h.	MCP type – GCNA-1391, motor (DVDA3 173/109-6-8-3 AMO5) - with oil lubricant Capacity – 22000 m^3/h, average time to failure – not less 18000 h.	MCP type – GCNA-1391, motor (DVDA3 173/109-6-8-3 AMO5) - with oil lubricant Capacity – 22000 m^3/h, average time to failure – not less 18000 h.

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
			Lifetime – not less 30 y, material – stainless steel	Lifetime – not less 30 y, material – stainless steel	Lifetime – not less 40 y, material – stainless steel
		Nominal pressure in primary circuit	15,7 MPa	15,7 MPa	15,7 MPa
		Design pressure in primary circuit	17,64 MPa	17,64 MPa	17,64 MPa
		Reactor outlet temperature	321 °C	321 °C	321 °C
		LBB concept measures implementation	There are extra means to detect leakages and bring the plant in a safe state	For pipelines of primary circuit with DN 200 and more, for steamlines with DN 600 and for feedwater pipelines	For main coolant pipelines, for ECCS passive part pipelines and connection pipeline of the pressurising system
7	Control rods system		Travel of absorbing rods is provided by means of CPS CR drive (SHEM-3), which represents a pitch electromagnetic drive	Travel of absorbing rods is provided by means of CPS CR drive (SHEM-3), which represents a pitch electromagnetic drive	Travel of absorbing rods is provided by means of CPS CR drive (SHEM-3), which represents a pitch electromagnetic drive
8	Steam generator	Number and type	4×PGV-1000M	4×PGV-1000M	4×PGV-1000M
		Steam capacity	1536 t/h (at Nnom=104%)	1470 t/h	1470 t/h
		Design lifetime	40 years	40 years	40 years
		Pilot operated relief safety valves	2 relief safety valves per each steam generator	2 relief safety valves per each steam generator	2 relief safety valves per each steam generator

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
		Nominal steam pressure	6,27 MPa	… MPa	… MPa
		Design pressure in SG	7,84 MPa	7,84 MPa	… MPa
		Outlet steam temperature	278,5 °C	… °C	… °C
9	**Safety systems**	Emergency boron injection system	3x100%, 1 pump per each channel Nom. pressure – 16 MPa Max flow rate – 6,3 m3/h	4x100%, 1 pump per each channel	4x50%, 1 pump per each channel
		Emergency steam-gas removal system	3x100%	4 x 100%	4 x 100%
		Emergency core cooling system of high-pressure (HP ECCS)	2 subsystems, 1 pump per each channel Nom. pressure – 9,8MPa Max flow rate – 235m3/h	4x100%, 1 pump per each channel Nom. pressure – 7,9 MPa Max flow rate – 260 m3/h	Individual system, 1 pump per each channel Nom. pressure – 7,9 MPa Max flow rate – 260 m3/h
		Emergency core cooling system of low-pressure (LP ECCS)	Individual system, 1 pump per each channel Nom. pressure –2,26 MPa Max flow rate – 800 m3/h	4x100%, 1 pump per each channel Nom. pressure –2,5 MPa Max flow rate – 900 m3/h Part of LP ECCS fulfils function of the normal operation – decay heat removal	Individual system, 1 pump per each channel Nom. pressure –2,5 MPa Max flow rate – 900 m3/h Part of LP ECCS fulfils function of the normal operation – decay heat removal – 2x100% coupled JNG-JNA trains

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
		Hydro accumulators	The 1st stage hydro accumulators - 4 x 60 m3 of each, - starting pressure 5.9 MPa	The 1st stage hydro accumulators - 4x 50 m3 of each, - starting pressure 5.9 MPa The 2nd stage hydro accumulators - 8 x 120 m3 each - in standby mode at atmospheric pressure	The 1st stage hydro accumulators - 4x 50 m3 of each, - starting pressure 5.9 MPa
		Automatic pressure relief system	3 PRZ PORV - with remotely controlled from MCR or ECR additional control line for decreasing pressure in primary circuit to 1.0 MPa	3 PRZ PORV - with remotely controlled from MCR or ECR additional control line for decreasing pressure in primary circuit to 1.0 MPa	3 PRZ PORV - with remotely controlled from MCR or ECR additional control line for decreasing pressure in primary circuit to 1.0 MPa
		Emergency feed water system or emergency cool down system	Emergency feed water system - 4 x 100% - 1 water tank per each channel - 1 pump per each channel	Closed-loop steam generator emergency cool down system - 4 x 100% - 1 water tank per each channel - 1 pump per each channel Part of SG-ECS fulfils function of the normal operation – SG blowdown and purification	Emergency feed water system - 4 x 100% - 1 water tank per each channel - 1 pump per each channel
		Steam generator heat removal system	None	Steam generator passive heat removal system - 4 x 33% - air-cooled	None

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
		Emergency heat removal means	A set of portable equipment including motor-driven pumps for supply of cooling water	In addition to PHRS and 2nd stage hydro accumulators to handle extended SBO, as abundant measure following additional engineering means are provided: - seismically qualified water tank with capacity of 10000 m3 (for two units) for make-up to SG, Fuel pool and Core Catcher$ - mobile air-cooled diesel generator for power supply to essential valves, mobile pumps and monitoring requirements etc; - seismically qualified borated water tank which can be replenished quickly to make-up to primary systems.	A set of portable equipment including motor-driven pumps for supply of cooling water with low flowrate (up to 80 m3/h) to steam generators and spent fuel pool to cool the primary circuit and spent fuel pool. The pump is connected via flexible sleeves to specially provided fittings on cooling water pipes. The cooling water is provided from the demineralised water reserve of not less than 2800m3 for water supply to SG and make-up of fuel pool during 72 hours.
		Number and type of passive catalytic hydrogen recombiners (used for BDBA conditions)	- 67 x RVK-1000 - 53x RVK-500	152 x RVK-1000 2xRVK-500	- 44 x (PARQX150 or PARQX75) designed by the Chinese Nuclear Power Research and Design Institute.
		Spray system in containment	4 x 50%, controlled by operator	4 x 100%, i pump for each channel	4 x 50%, controlled by operator

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
10	Means for residual heat removal		LP ECCS and BRU-K - in the first stage, the cooldown is provided by SG steam dump to turbine condensers; - in the second stage, the reactor is cooled by emergency and planned cooldown system	LP ECCS - and BRU-K	- JNA (RHR system) pipelines - containment spray pumps
11	Containment	Type of containment	Single containment	Double containment	Double containment
		Height	54 m	61.7 m	64.5m
		Inner diameter	45 m	44.0 m	44.0 m
		Design pressure	- 0,5 MPa - to 0,7 MPa - short-term at BDBA	- 0,5 MPa	- 0,5 MPa
		Leak tightness	< 0.3% at design pressure	< 0.3% at design pressure	<0.3% at design pressure
12	Corium catcher		None	Sacrifice material – steel+multi-component system on the base of Fe and Al oxides with addition of Gd oxide Heat from the catcher is transferred to water (passive cooling) collected around the catcher in containment sump	Sacrifice material – steel+multicomponent system on the base of Fe and Al oxides with addition of Gd oxide Melted core is cooled by the water in the sectional heat exchanger as a part of catcher. The water is supplied from the reactor inspection shaft water emergency use system to the

No.	Main Category	Sub Category	Russia Balakovo NPP Unit 4	India KK NPP Units 1&2	China Tianwan NPP Units 3&4
					core catcher. The water in the heat exchanger gets heated up and starts boiling. Steam is removed through discharge channels to the atmosphere in the reactor building.
13	Turbine	Type	K 1000-60/1500-2	K 1000-60/3000-2	TC6F-54
		Thermal cycle	HPC + 3LPC	HPC + 3LPC	HPC + 3LPC
		BRU-K (turbine bypass valve) output	BRU-K 60 %	BRU-K 60 %	BRU-K 60 %
14	Electrical equipments	Direct current power supply	Three accumulating batteries in emergency power supply system - rated voltage 220 V - 106 cells in each battery	EPS 12 x 1500 Ah CPS 2 x 1500 Ah Normal Operation System 4 x 1500 Ah	EPS 4 x 400 Ah CPS 1 x 2600 Ah Reliable power supply normal operation system 2x200 + 2x420
		Generator with the internal combustion turbine drive	None	XX KVa Mobile DG for DEC scenario	150 kW mobile DG for BDBA conditions
		Diesel generator s for emergency Power Supply	3 x 5600 kW	4 x 6300 MW	4 x 5500kW